DESIGN OF OPTIMAL ENERGY EFFICIENT AND RELIABLE SMART MICROGRID

SHORT SYNOPSIS

Submitted in partial fulfillment of the requirement of the degree of

DOCTOR OF PHILOSOPHY

to

Manav Rachna International Institute of Research and Studies
(Deemed to be University)

by

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Certificate

I hereby declare that the short synopsis "Design of optimal energy efficient and reliable Smart Microgrid" being submitted in partial fulfillment of the requirement for the degree of Doctor of Philosophy in Electrical and Electronics Department under faculty of Engineering and Technology of Manav Rachna International Institute of Research & Studies, Faridabad during the academic year 2018-2019.

It is a bona fide record of original work carried out under the supervision of Dr. Mahendra Kumar Soni & Joint Supervisor Dr. Dheeraj Joshi and has not been submitted in full or part to any other university or institute for degree or diploma. Further, it is certified that short synopsis is plagiarism free and proof has been submitted.

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ABSTRACT

Adding digitization, control, advanced resources and operations in the electric grid to make it smarter is smart grid. The fossil fuels are getting depleted so adding renewable energy sources for generation to adding smart appliances at consumer side is need of the time. The smart grid needs to be energy efficient, reliable and secure for transfer of electricity from generation to consumers and flow of information from consumer to generation. This two-way flow of information enhances the need for wireless sensor network in transmission and distribution side. The technology applied for smart grid is still in process of implementation. There are a lot of challenges for its implementations like two-way flow of information, adding renewable resources, adding smart appliances at consumer side, reliable and cost-effective way of flow of information, self-healing etc. The communication is leading component within smart grid for optimize the use of electrical energy in financial prospective and reliability of systems.

The idea to replace the existing system with new improved optimized smart power grid infrastructure rejuvenates multiple challenges, threats to effectively integrate smartness without impacting the use of existing grid.

The various indices for visualizing the performance of the integrated system are energy efficient system, reliable, secure and flexible. A Protocol for smart grid needs to be designed for managing demand and supply as per customer needs and use of renewable energy. Markov process and Poisson's method are used for two-way communication and reducing average cost of energy production at main grid. The electricity generation at consumer end from renewable sources, is stored in batteries and used when required and send back to main grid if excess. The average cost of power production is calculated, and appropriate action is suggested to increase the efficiency of the entire system. In this research work, the two main areas considered as performances indices are energy efficient and reliable smart microgrid.

Keywords: Smart grid, digitalization, renewable sources, two-way communication, energy efficient, reliable.

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1. Introduction

Smart Grid is a two-way dialogue network for not only delivering electricity but also includes communication, control, computers, automation and new technologies and tools working together from producers to consumers. In traditional electrical grid, the sources are fossil fuel fired power stations (gas, oil-fired and large coal power stations), Nuclear power station and hydro-electric power plants in mountains whereas in smart grid, renewable sources of energy are used. Smart is a two-way communication between producer and consumers. Smart grid uses smart appliances and control. Smart grid enables self-healing without intervention of technicians.

As depicted in fig1 smart grid is used to establish reliable, secure and energy efficient electric grid. The deployment of new sources of electricity i.e renewable sources and integration of new technologies at generation, transmission, distribution and consumer side. Adding smartness is integration of smart devices and consumer appliances. The deployment of advanced electricity storage technologies and maintaining the consumption of electricity at peak time. In smart grid, the consumption of electricity should be regulated by managing the consumption of electricity at peak hours that is maintaining demand and response.

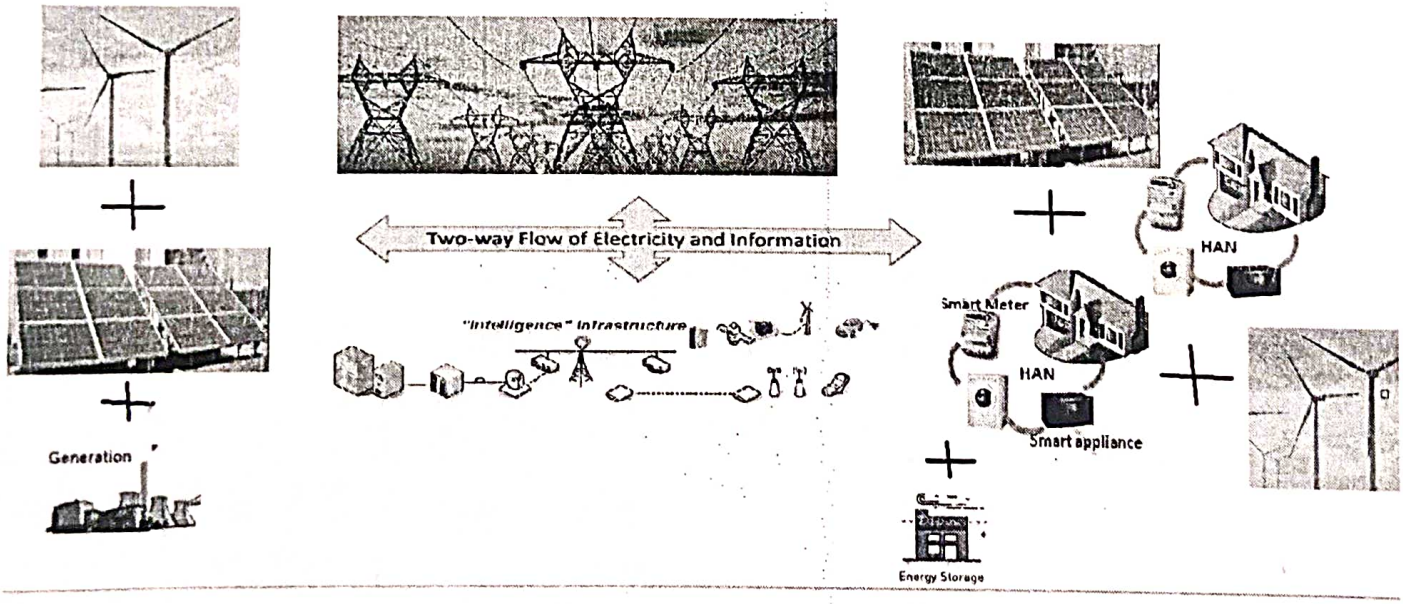


Fig 1. Architecture of Smart Grid

History

The legacy electric grid which was installed in around 1880. The electric grid flows power from production to consumer which is unidirectional flow of power distribution, transmission and demand-based control. The existing grid is formed from the local grids getting highly interconnected over time. The first AC power grid system situated in Great Barrington, Massachusetts in around 1886.

Existing electric grid has fixed tariffs due to limited data collection and processing capabilities and dual tariff arrangement for electricity bill. Dual tariff means that lower the cost of electricity at night time as the consumption is very low at that time and higher the rate of electricity at peak times. In between 1970 to 1990, there are multiple cases of blackouts, brownouts and power cuts due to supply couldn't keep up with the high demand at peak times. In the end of 20^{th} century, reliability of electricity is required. So, towards 21^{st} century, multiple developing countries become pioneer for smart grid.

Features of Smart Grid

1. Two-way communication: It includes digitization using wireless sensor networks. The flow of information in real time between consumers and producer.
2. More energy Efficient and Greener: Adding renewable resources like solar cells, PV panels, wind energy etc.
3. Manage electricity usage: Start/ Stop of appliances at variable rate of electricity.
4. Smart Appliances: Smart meters, wireless sensor networks at transmission and distribution side.
5. Lower energy bills.
6. Data and Automation: Automation is needed at transmission, distribution and consumer side.
7. Consumer engagement: If consumer is aware of hourly rate of electricity, then consumer will use the appliances that are at most important at that instant of time.
8. Reduce operating cost.
9. Real time analytics.
10. Predictability manage electricity production: The failure rate is estimated using various prediction-based algorithms to get the mathematical knowledge about the

number of standby generators required. it is possible to predict how many standby generators need to be used, to reach a certain failure rate.

11. Distribution Intelligence.
12. Automatic re-routing and restoring.
13. Reduce greenhouse gas emission as sustainable energy generation
14. Demand response optimization.
15. Reliability: Reliability estimated mostly by Markov processes through state estimation which improves fault deletion and allow self-healing.
16. Energy Efficiency: To efficiently transfer of electricity and information from consumers to production vis-a-versa in energy efficient way.
17. Flexibility.

2. Literature Review

The literature survey acquaints me with the important concepts of smart electricity grid systems and to study existing techniques used in smart grid.

The renewable resources like wind power, thermal resources and pumped storage are mixed to minimize the cost of operation of electric power plant. The authors (Yuan, Zhou and Li 2015) proposed a "two-stage generation scheduling approach to optimize the operating cost". This research is jointly implemented at "electric power university of china and university of Birmingham, UK".

Around the world, there are multiple people are interested in smart grid benefits. The smart grid has multiple benefits which was explained in multiple presentations. The presenter (Mohamed E. 2016) tries to make the world understands "technical, socio-economical, environmental and other non-tangible benefits to society". The real time implementation of infrastructure that will respond to in real time and take proactive actions to articulate the challenges of future power system. The author presented in "Dalhousie University in Nova Scotia Canada".

The deployment of smart grid is major concern for researchers as it impacts not only economic consideration analysis but includes other factors like energy, environmental and social impact etc. The architecture of smart cities depends on optimizing the use of smart energy and methodologies. The parameters considered for deployment of smart grid are

discussed in it.The various aspects are considered in the form of metrics and then evaluation done based on CBA considered. The development of smart cities is a dream project which includes deployment of smart things includes financial benefit analysis in deploying and managing it in wider prospective. The authors (Marcelo Masera 2018) explained the wider prospective of smart grid from deployment to support and maintenance. There are various challenges of implementation includes security of grid, societal impact, environmental effects, financial study, only crucial components can be used etc. This paper explains these points in detail.

The communication prospective needs to understand before starting on smart grid. The energy packets are mixed with data packets to supply the information along with existing energy. Various authors work on implementation of energy with data ((Tsoukalas, Lefteri& Gao, Rong.2008). The sources of energy generation are separated and various methods for operating, controlling these using multiple strategies of voltage and stability control are studied by authors (X. P. Zhang 2008) in this paper. The threats of implementing this large scale deployment of smart electricity includes robustness, reliable, flexible, consumer concentric, financial benefits and most important security of smart electricity distribution explained by authors (conditions (Massoud, B. F. Wollenberg 2009).

The data, information, internet and communication in smart grid are mostly addressed terms in all the papers related to smart grid. The opportunities with multiple issues are discussed in detail. The current scenario of grid is studied by looking at future prospective which addresses multiple open research questions. The existing environment for implementing the new smarter technologies are studied along with issues with smart grid communication to get better few of futuristic issues.

The demand should be same as supplier requirement as storage of energy consumes more finance and energy depletes with time is also a concern. The paper written by authors (Basumatary, Jwngsar& Singh, Brijendra& Madhava Gore, Manoj.2018) studied "the pattern of electricity demand in MNIT, Allahbad". The technique used by author includes "bottom up load modelling to estimate the demand of electricity and also proposes the load scheduling technique to create the demand curve based on rescheduling the usage of load appliances" (Basumatary, Jwngsar& Singh, Brijendra& Madhava Gore, Manoj.2018).

The smart grid is a great idea and researchers are interested in implementing this in india also.

"Savvy lattice approaches embraced worldwide and a short survey of different continuous ventures in India and standards set by Indian government for the actualizing organization of cutting-edge metering foundation (AMI)" is studied by authors (Rahul Yadav, Mr. Kushaldeep Sharma, Deepika Chauhan2018). The smart grid pilot study in India includes the technology integration. The technicalities are studied with interest of partners with enthusiasm of creating change with responsibility of reliable, safe, versatile, feasible and pure biological gains that improves the quality of implementation and services.

Some researchers are interested in power electronics in smart grid distribution power systems.

The power electronics capabilities required for distributed generation systems in smart grid to convert the generated power into useful power that can be directly interconnected with the utility grid and/or that can be used for consumer applications. Because of the enhancement and the different power ranges of power electronics devices, the development of advanced power electronic interface that is scalable to meet different power requirements, with modular design, lower cost, and improved reliability, will improve the overall performance and durability of smart grid distributed power systems (Bayoumi, Ehab. 2016).

The reliability is important aspect of smart grid performance metrices. To evaluate the reliability of smart grid, various techniques are used like "Intelligent State Space Pruning with local search for power system reliability evaluation". This new method is used to evaluate the reliability of the smart grid and various optimization techniques are also used like PSO (R. C. Green 2012).

The reliability is studied in multiple papers based on various components used in smart grid. The distributed states are estimated over unreliable communication networks in smart grid using "interconnected optimal filtering problem for distributed dynamic state estimation considering packet losses" (M. Rana, L. Li and S. W. Su 2017).

The reliability is evaluated based on components reliabilities. There are multiple components are used in smart grid which has multiple mode of operation also. PV panels are of small cost so these are mostly used as solar source of energy. There are two operating stages of PV panels are redundant mode and parallel mode of operation. The DV to DV converters are

used with renewable resources in mixed like PV panels and wind generation system to calculate the reliability of the systems. There are two indexes to calculate the reliability of any system as MPPT and MTTF i.e. maximum power point tracking and maximum time to transfer respectively. The reliability is calculated using both performance indices for boost DC to DC converter using PV panels. The two modes are considering for operation are parallel and redundant studied by these authors (Farid, Hamzeh2016).

Optimum Deployment using Genetic Algorithm for performance evaluation of wireless sensing nodes explains the use of optimization tools in increasing the performance of wireless sensor networks (G.L. Pahuja 2011). The performance indices are considered as uniform deployment, coverage, time of deployment etc. The coverage is calculated based on the monte carlo method. The coverage and uniformity are optimized using genetic algorithm.

As wireless sensor networks are used in smart grid also so the optimization of energy efficiency in smart grid using optimization tools can be implemented also.

3. Description of Broad Area

The existing electric grid has multiple issues like lack of advanced resources and use of previous technologies which will not cater the need of future generations so to fulfil the needs of upcoming generation, smart grid is needed. Smart grid added the use of renewable resources which reduces the impact of co2 emission by fossil fuels and make the new generation using green technologies i.egreenhouse impact can be reduced. The existing system is getting obsolete in near future. The customer engagement is also added in smart grid. There are numerous benefits of smart grid whereas few also thinks the disadvantages of smart grid as higher energy prices based on high investment. The data security issues or problems due to new technologies added in the smart grid like wireless sensor network throughout the transmission and distribution side. The data misuse is also considered as security is an important aspect to be considered. The loss of jobs due to automation added in the transmission and distribution side. The self-healing capabilities can reduce the number of workers needed to manually rectify the issue. The insure of energy supply placed doubt in implementing the smart grid. There are lot of issues/doubts in the implementation of smart grid, but Smart grid has multiple benefits to the society. The broader area of study is smart grid. Smart grid includes generation, transmission, distribution and consumer side. There are

multiple performance indices includes energy efficiency, reliability, security, quality of communication and services. The wireless sensor network placed in between the generation to consumer side enhances the quality of communication through reliable sending of data and processing. The renewable sources that can be considered are solar energy, wind energy, PV panels, biofuel etc. The variation in these resources will be monitored in every or two hours and the energy generated by these resources should be stored in some batteries for later use. The two-way flow of information increased the credibility of the information flowed to the correct user.

The multiple renewable sources have been added as generation sources at microgrid level. These resources are used at the consumer end and the two-way flow of energy is considered. The excess of energy generated at consumer side is flowed from consumer to provider and there is a check if the energy produced at consumer side is less than the energy required then microgrid performs its controlling operation. The control at microgrid level checks the energy required with the energy generated. If the energy generated is less than the required energy, then the remaining energy is requested from generating station and if there is excess at consumer side then energy is supplied to the generation station. The amount of energy withdraw from consumer is deducted from the bill of consumer. Along with energy, there is flow of information from consumer to producer and producer to consumer through wireless sensor networks. The prediction of energy consumed by single user is estimated based on that user previous bills. The amount of use of fossil fuels is regulated based on that estimation. The amount of energy generated at that instant of time should be consumed within that time otherwise there is a loss of energy. To reduce this loss of energy, the estimation will provide information of each consumer. So, in smart grid, every consumer is considered, and various routing algorithms are created to enhance the performance of the smart grid. The various routing algorithms are studied, and a new algorithm will be created that will adhere the features of smart grid. The performance should be evaluated based on performance indices includes reliability, ease of deployment and energy efficiency primarily. To explain the smart grid, both the power generating plant and consumer can use the renewable resources. The various routing algorithms are placed at transmission and distribution side.

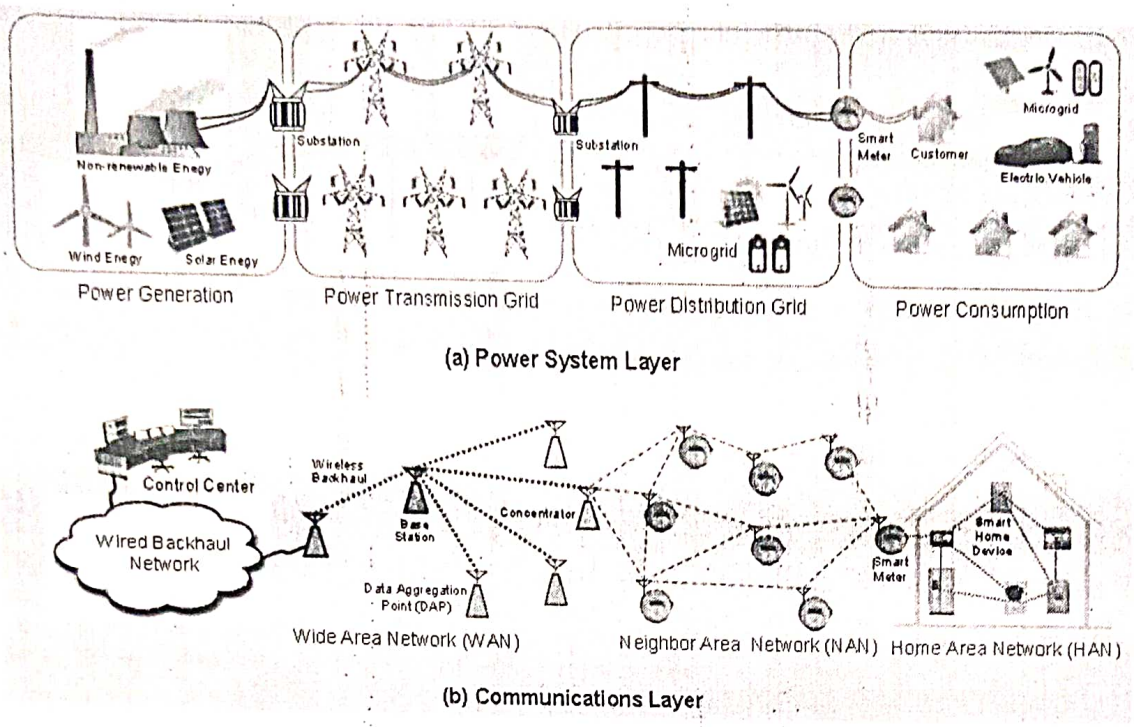


Figure 2 Layered structure of Smart grid

The smart grid is divided into power system layer or communication layer. The power system is same as the existing legacy electric grid where only renewable sources are added along with smart appliances at consumer side. The second layer is communication layer that will explain in detail below:

There are three network areas as wide area network, neighborhood area network and home area network. There are multiple routing algorithms can be used to home area network as there are low energy, self-organization, ensure privacy and information and self-configuration is present over there. Routing Protocol for Low power lossy network (T. Winter 2012) is de-facto routing protocol for home area networks. Ad-hoc on-demand distance vector routing is also used in home area networks mostly (Perkins 1999). The average end to end delay of traffic with distance of nodes to the gateway is 160 millisec for RPL an d1870 millisec for AODV algorithms. The neighbourhood area network is mostly in transmission and distribution grid which carry information from meter to the utility centre. The performance indices considered is quality of service (QoS) as the network has enough capabilities to support QoS requirements of the users. RPL can also be used here as it supports multiple routing metrices, multiple communication types and most imp security. The distributed autonomous depth first routing can be also be used here. In smart grid,

neighbourhood to neighbourhood area network is used as it is at highest level of hierarchy and it supports high bandwidth for transferring large volume of data with high security. The multi gate routing, multi mesh routing and real time traffic scheduling techniques are considered here as routing protocols. It is based on multiple paths.

The smart appliances are used in the consumer side as smart meters, electric vehicle and controlling the on and off appliances at peak hours. The rate of electricity should be communicated to the consumer in real time and the action of the use of appliances should be done accordingly.

4. Problem Identification

Smart grid is most promising topic around the world. The smart appliances are started manufacturing all around the world. There are multiple researchers are working on this topic around the world. There are multiple technologies are used by various researcher to resolve the issues arise on the path of deployment of smart grid. Along with deploying renewable resources at production level and consumer side, the automation goes hand on hand. The automation is applied at transmission and distribution side to enhance the credibility of smart grid. The problem discussed in smart grid is different for different countries. For south Africa, it is increased use of renewable generation, decarboning electricity generation and improved network reliability and Availability. For Asian countries, smart grid efforts are related to generation expansion, transmission expansion and reducing emissions.

The smart grid is expected to be implemented fully by around 2030 around the world. There is not much work is done to implement it into real world, so it is quite a new topic although it is in discussion around the world. The implementation is in progress and optimization idea are also under discussions. The work done in smart grid under multiple performance indices are to create a grid with high reliability, security and energy efficient. The work is carried out using different technologies and modes. Some uses other technologies which are implemented in other applications and try to implement in smart grid also to get the better results that are realistic also.

The papers studied till now related to energy efficiency of the system have used either single generation source or if multiple sources are used then cost is not considered. So, my work will not only include multiple renewable sources of energy but also cost is considered. The

energy efficient system with reliability of the microgrid is evaluated and optimized. The work done in the papers are subjected to the conditions like low power lossy networks are applied to when lossy networks are considered. The existing algorithms can be used only in one of the these: home area networks, wide area network or neighbourhood area network. There is no work done that can be implemented to all these networks. So, there should be protocol that can be used in any area and any distance. The customization of data can be done to use the algorithm at various places. The protocol should be optimized in energy efficiency and at least reliability of the smart grid. The various generation sources can be used to enhance the credibility of the smart grid like solar, wind, bio gas, bio mass, PV panel etc.
The data should be collected in real time and optimize the results in real time using various optimization techniques.

5. Objectives of Research

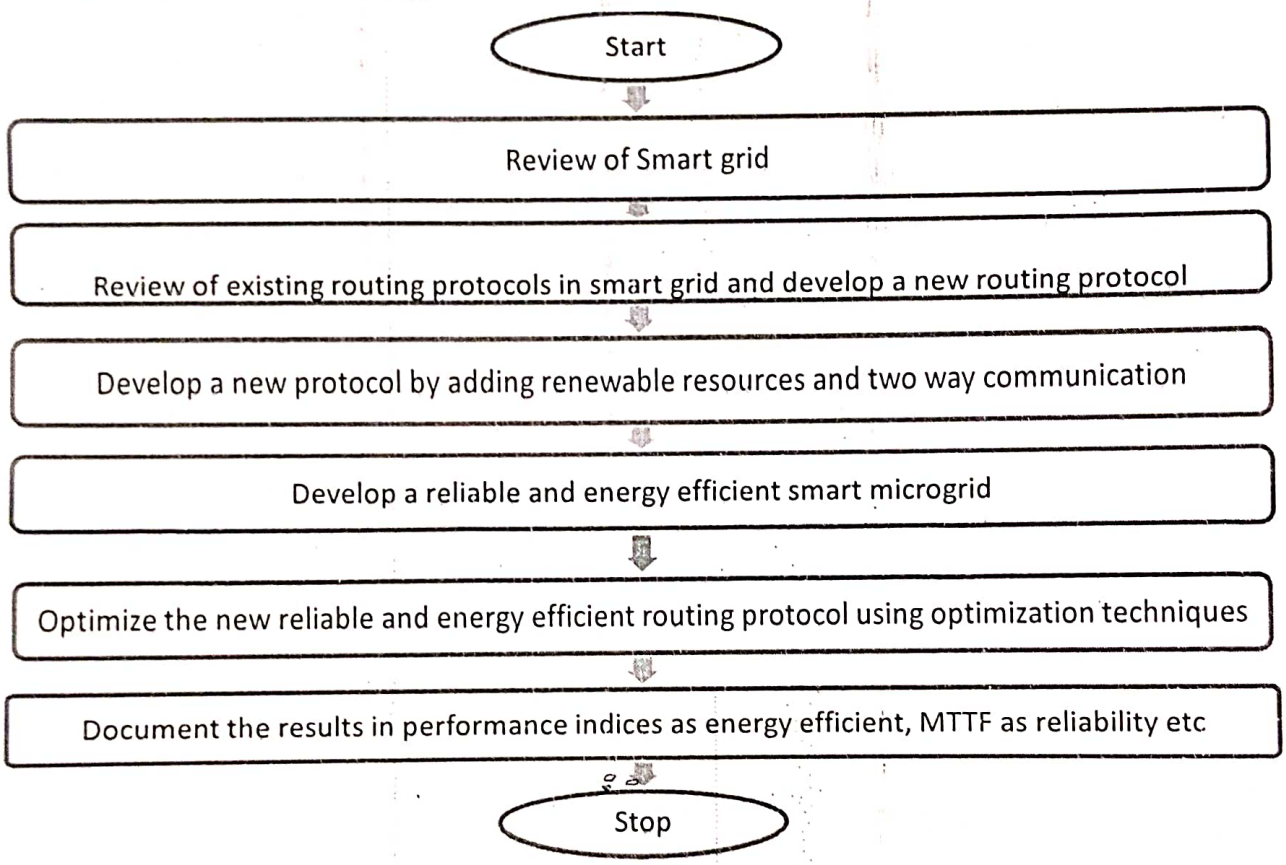
The objective of this research is to create a technique that can be implemented in real world and that will benefit the society in near future. Smart grid is new topic as it is not implemented yet so if there is some new work done in this area that can be used for implementation and benefit the society. The essential part of this research is to contribute in fulfilling the constraints of the smart grid i.e adding renewable resources as much as possible, customer engagement, demand supply deficit should be reduced and use of smart appliances that includes internet of things (IoT). The on/off of appliances should be control and used uniformly to reduce the usage of appliance on peak times. The controlling at microgrid level is considered here and reliable microgrid should be designed. The performance parameters are considered as increase in energy efficiency, reduce the usage of fossil fuels, two communication, increase in reliability of the system and finally optimize the performance of the microgrid by using multiple optimization techniques.

To achieve the above-mentioned aim, research objectives are outlined below:

1. To perform extensive literature review of smart grid that includes study smart grid at generation side to enable the use of renewable multiple resources, adding automation at transmission and distribution, study the use and control of smart appliance at consumer side

2. To study the various routing protocols deployed on home area network, wide area network and neighborhood area network.
3. To design a new protocol satisfying the need of smart grid i.e high energy efficiency and optimal cost.
4. To increase the reliability of smart microgrid.

6. Proposed Methodology


Start
Review of Smart grid
Review of existing routing protocols in smart grid and develop a new routing protocol
Develop a new protocol by adding renewable resources and two way communication
Develop a reliable and energy efficient smart microgrid
Optimize the new reliable and energy efficient routing protocol using optimization techniques
Document the results in performance indices as energy efficient, MTTF as reliability etc
Stop

A new routing algorithm needs to be developed after reviewing the existing protocols. The two-way communication is considered along with renewable resources in the new protocol. The reliable and energy efficient smart microgrid will be developed and existing optimization techniques will be used. The results are documented and presented later.

7. Expected Outcome of the Research

There are valuable outcomes of this research work could make to theEngineering area:

1. To perform extensive literature review on the existing work in smart grid at various countries including India.
2. Develop a new protocol for smart grid after studying existing routing protocols of smart grid.
3. Increase energy efficiency of the new protocol by apply optimization techniques and by considering cost. The optimization used is neural networks, genetic algorithm, particle swarm optimization etc. The feature of smart grid should be included like two-way communication from producer to consumer, demand supply management, addition of renewable resources like solar energy, wind energy and addition of battery to store the excess energy generated.
4. Develop a reliable smart microgrid and optimize it.

8. Proposed Time Frame

Time Frame	Dec 16-June 17			July-Dec 17			Jan -June 18			July-Dec 18			Jan-June 2019			July-Dec 19			Mar 202	
Months	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	37	38
Course Work																				
Extensive Literature Survey																				
Problem Statement																				
"To study the performance indices for smart grid"																				
To design a new protocol for smart grid																				
Develop and Analyse energy efficient routing protocol for smart grid after study existing routing techniques																				

Develop a reliable smart microgrid																				
Optimize using existing optimization techniques like GA, neural networks etc																				
Publication Related to the work																				
Detail Writing and submission report																				

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